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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 426.

SEAPLANE FLOATS AND HULLS.*

By H. Herrmann.

PART I.

Introduction

Seaplanes have been built for the last twelve to fourteen years and enormous experience has been gained. The present report is the first systematic digest of the important technical data available on this subject.

In the earlier days of seaplane development, floats and hulls were exclusively built by machine and aircraft constructors. Their seaplanes had a low degree of seaworthiness. Conditions rapidly changed in all countries, as soon as the matter was taken up by expert naval engineers. This important fact should be taken into consideration when working out programs for aeronautical engineering courses. These courses should be held only at universities having a shipbuilding department.

Since the war, seaplanes have been built only by special firms, partly because they have a wider technical experience and also because the demand for seaplanes is smaller than for airplanes (Figs. 1-4).

*From "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," December, 1926, pp.126-152.

TABLE I.

Numerical List of Seaplanes in 1925, not Including Training Airplanes

	Pursuit airplanes	Bombing and torpedo airplanes	Observation airplanes	Flying boats	Total	Number of airplanes	Ratio of seaplanes to airplanes
England without colonies	54	63	45	18	180	700	1: 3.8
France	12	84	24	12	132	1410	1:10.7
Italy			176		176	1133	1: 6.5
Russia	30	30	120		180	630	1: 3.5
America	131	66	264	264	461	848	1: 1.8
Japan			200		200	270	1: 1.4
					1339	4991	

There are two methods for a government to develop good seaplanes: In the first instance, by placing an order or calling for bids, thereby leaving it to the designer to develop his own ideas. The result is the creation of a great variety of types. In this case, however, efforts are not directed toward a systematic development. Consequently, many inadequate types are obtained.

In the second instance, orders are placed or bids called for, but the designer is limited by strict specification. In this case few types are created, but all efforts are directed toward their development. As a result of this "limited development," perfectly practical features, high efficiency and economical methods of production are obtained.

America is the most successful exponent of "limited development."* Next comes England. France stands for the other system. Italy, Russia, and Japan keep somewhere between the two. Owing to treaty restrictions, Germany has unfortunately adopted free development. The danger of this system is but slightly reduced by the systematic working methods of German industry.

The objections to the system of limited development are invalidated by the decided success of the United States. The success of this system actually depends on a single condition, namely, that the nation adopting it should not have reached its culminating point of development. If this is the case, no lasting superiority is likely to be insured by either free or limited development.

Characteristics and Graphic Representation of Water Resistance

With increasing speed, the water resistance or drag of a normal seaplane first reaches a maximum value and then falls to zero at take-off speed. The resistance decreases when the hull or floats emerge or "rise on their step." At the same time, the water forces develop a considerable angle of attack of the sea-

*Richardson, H. C. - Development in Naval Aeronautics. "Journal of the Society of Automotive Engineers," Nov. 1924, p. 412. Discussion of Paper, March, 1925, of the S.A.E., p. 361.

plane. At 40% of the take-off speed, the wings support only 16% of the weight. Water resistance can be represented as dependent on the total weight and on the load supported by the water (Fig. 2). A factor of comparison can readily be obtained by expressing the resistance (Fig. 1) in per cent of the total weight. The factor lies usually between 20 and 30%. The resistance curve changes immediately, if the seaplane is more heavily loaded for the same take-off speed. The same result is obtained by changing the take-off speed or both the load and the take-off speed simultaneously, which is ususally the case. The magnitude of the variation is shown in Figs. 3-5. The numbers refer to a pair of twin floats. Conditions are similar for flying boats.

The procedures outlined above are not sufficient for comparing two pairs of floats or two flying boats. In this connection, G. Madelung has made a useful suggestion. In Fig. 6, the speeds are plotted as abscissas. The oblique lines a, b, c, and d give the weight resting on the water for different speeds. The water resistance is plotted on these lines as a fraction of the total weight at rest. Points of equal resistance are then connected and the system of light lines is thus obtained. By means of these lines the water-resistance curve, plotted in Fig. 1, can be read for any load and for any take-off speed, after drawing the corresponding straight line.

Characteristics can be easily computed from the lines of such a diagram. An appropriate choice of the initial displacement, on which the numbers are based, would permit making a good comparison of the different lines. Of course, no comparison can be made, if the datum for two different lines is chosen arbitrarily. An entirely nondimensional representation can be obtained when the speed is divided by a linear dimension. It is very difficult to find a universally applicable dimension, which will not disturb the comparison. For either single-float or twin-float seaplanes the water-resistance datum is given by the total float capacity. As far as seaworthiness is concerned, the capacity is usually 1.8-2.2 times the displacement at rest. The water resistance of twin-floats of 2 tons total capacity is shown in Fig. 7. The shape of the float is shown in Fig. 8.

Without changing its submerged portion, a flying boat may be provided with a cabin hull or with a military hull. The total capacity of the hull is thus considerably changed. Also the same hull is often loaded to a different height. In this case the determination of the datum line is rather difficult and requires careful consideration.

Comparison of Model Tank Test with Actual Performance

	Actual hull	Model
(1)	Propeller thrust overcomes both water- and air-resistance, accelerates seaplane and develops a nose-heavy moment.	Both thrust and water resistance act on model according to height of propeller. Acceleration thrust lacking. Consequently very slight change of trim and resistance. Variation within measurement accuracy.
(2)	Water resistance depends largely on flow under hull, which changes slowly with increasing speed.	There is no acceleration. When there is acceleration, the hull always travels with a flow diagram corresponding to a lower speed. Variation of water resistance is within range of measurement accuracy.
(3)	Part of water resistance is due to friction subject to the Reynolds law.	Owing to friction, water resistance measurements of model are too high and must be corrected.
(4)	Controls are ineffective at low speeds, but work satisfactorily at high speeds.	At low speeds the model is tested untrimmed and at an arbitrarily chosen angle. If this angle proves unfavorable at higher speeds, it is then given a predetermined value.
(5)	Variation of lift is effected by altering the trim.	Not taken into consideration, since it is difficult to realize and has no effect on result.

Laws of Similarity and Theory of Model Tests

Water resistance is determined by model tests in a naval model tank. The application of the results thus obtained to full-sized hulls and floats is based on the Froude law of similarity.* The requirements of this law are given in Table II. Owing to greater friction, the model produces more spray than the actual hull, but conditions are not very different. As a whole, the results obtained in model tank tests form a satisfactory basis for the development of seaplane designs. No other method is available at present nor likely to be found within the very near future. Formerly models were tested for different take-off speeds and loads and the corresponding resistance curves were plotted, as shown in Fig. 3. Now the resistance is measured in function of the speed for three or four loads resting on the water, and Madelung's diagram is plotted accordingly. Owing to the detrimental effect of friction,** the model must be rather large. Therefore, preference is given in Germany to the Hamburg naval tank*** (the largest in the world), instead of the Prussian hydraulic and naval tank. The comparative tests made by

*Weber, M., Fundamental principles of mechanics of similarity and their application to model tests. "Yearbook of the Shipbuilding Society," 1919, p. 355.

**Kempf, G. and Kloess, H., Resistance of short surfaces. "Wharf, Shipping, Harbor," August 7, 1925, p. 435.

Kempf, G., Surface resistance. "Wharf, Shipping, Harbor," Oct. 22, 1924, p. 521.

***Popp, M., Measuring instruments and methods of the Hamburg shipbuilding water tank. "Wharf, Shipping, Harbor," June 7 & 22, 1922, pp. 335 & 367.

Baker* in England in 1918, are not sufficiently accurate.

TABLE II.

The Froude Model Law

	Symbols for		Unit	Conversion factor	Similarity formula	Conversion at a given λ
	Original	Model				
Length	L	l	m	λ	$L = l\,\lambda$	$\lambda = \lambda$
Time	T	t	s	τ	$T = t\,\tau$	$\tau = \sqrt{\lambda}$
Force (water resistance and landing shock)	K	k	kg	κ	$K = k\,\kappa$	$\kappa = \lambda^3$
Displacement	Vol	vol	m^3	λ^3	$Vol = vol\,\lambda^3$	λ^3
Mass	M	m	$kg\,\frac{s^2}{m}$	$\frac{\kappa\,\tau^2}{\lambda}$	$M = \frac{m\,\kappa\,\tau^2}{\lambda}$	λ^3
Speed	V	v	m/s	$\frac{\lambda}{\tau}$	$V = v\,\frac{\lambda}{T}$	$\sqrt{\lambda}$
Acceleration	B	b	m/s^2	$\frac{\lambda}{\tau^2}$	$B = b\,\frac{\lambda}{\tau^2}$	1
Work	A	a	mkg	$\lambda\,\kappa$	$A = a\,\lambda\,\kappa$	λ^4
Power	E	e	mkg/s	$\frac{\lambda\,\kappa}{\tau}$	$E = e\,\frac{\lambda\,\kappa}{\tau}$	$\lambda^{3.5}$
Angular velocity	Ω	ω	1/s	$\frac{1}{\tau}$	$\Omega = \omega\,\frac{1}{T}$	$\frac{1}{\sqrt{\lambda}}$
Angular acceleration	Ω'	ω'	$1/s^2$	$\frac{1}{\tau^2}$	$\Omega' = \omega'\,\frac{1}{\tau^2}$	$\frac{1}{\lambda}$
Torque	M	m	mkg	$\lambda\,\kappa$	$M = m\,\lambda\,\kappa$	λ^4

*Baker, G. S. Experiments with full-sized machines. British Advisory Committee for Aeronautics Reports and Memoranda No. 473, 1st series, Sept., 1918.

Process and Calculation of Take-Off

When the pilot turns on full throttle, the seaplane receives an acceleration from the propeller thrust. First there is only water resistance to be overcome. This increases to a maximum value which lies approximately around 35 to 45% of the take-off speed and 20 to 30% of the total weight (Fig. 1). Then it decreases again and becomes zero when the seaplane clears the water. The speed at which resistance is maximum is termed the "critical speed." At this speed the air resistance, which increases as the square of the speed, is approximately 16% of its value at the take-off speed. For older boats this equals 20%, or 1/5, and for modern boats, 10 to 12.5%, or 1/10 to 1/8 of the total weight. Thus the air resistance of older boats at the critical speed is 3.2%, and of modern boats, 1.6 to 2% of the total weight. Consequently, the water resistance of modern boats is approximately ten times the air resistance. The seaplane takes off when the propeller thrust exceeds the combined water and air resistance.

A result of the elevated position of the propeller, with reference to the center of gravity and especially to the waterline, is nose-heaviness, which depresses the bow. Certain bow shapes produce suction effects, due to the increased relative velocity of the water flow. The result is that many seaplanes nose down while taking off, before the critical speed is reached. This effect is counterbalanced by holding the elevator control back. When the critical speed is reached, the seaplane automatically assumes a larger angle, rises on the step and glides on the surface until the take-off speed is reached. The water resistance decreases simultaneously, provided the hull is of a satisfactory design. The stern then lies in a partly hollow water zone disturbed by the bottom of the float and with two divergent and successive waves, the entire load being supported by the step. In smooth water a local stress of 0.35 kg/cm² (4.98 lb./sq.in.) was measured on an English F.3 (Fig. 33), take-off speed 85 to 90 km/h (52.8 to 55.9 mi./hr.).* Waves of 75 cm (29.5 in.) height produced at the bow a local impact of 0.44 kg/cm² (6.26 lb./sq.in.).

At 40% of the take-off speed, i.e., at the mean critical speed, 16% of the total weight is supported by the wings. Yet the boat rises on the step under the action of the water and glides on the surface. Then the weight is gradually assumed by the wings and the hull is completely unloaded at the take-off speed. The formation of waves decreases also with the speed and disappears at the take-off. It is remarkable that flying boats acquire lateral stability as soon as they rise on the step, owing to the dynamic effect of the water forces.** The rudder

*Biplane flying boat with 2 Rolls-Royce engines:

Total weight,	5600 kg	(12,346 lb.)
Wing area,	132 m²	(1,421 sq.ft.)
Engine power,	2 x 348 HP.	
Wing loading,	42.4 kg/m²	(8.68 lb./sq.ft.)
Power "	7.07 kg/HP.	(15.37 lb./HP.)
Maximum speed,	146.00 km/h	(90.7 mi./hr.)
Ceiling,	2.4 km	(7,874 ft.)

**Wm. Froude National Tank Staff and A. D. Grigg - Experiments with models of seaplane floats (9th series). British Advisory Committee for Aeronautics R&M No. 188 Dec. 1915.

becomes effective shortly before the seaplane takes off, whereas the elevator takes effect much earlier under the influence of the propeller slip stream.

Normally a seaplane takes off and alights against the wind and waves. Very seldom, and only when there are waves without wind, small seaplanes start in troughs parallel to the waves, thus avoiding their blows. When the seaplane alights, the conditions are reversed. The seaplane glides on the surface of the water until its speed decreases to the critical speed. Then the hull submerges and the seaplane soon comes to rest. The mass multiplied by the retardation is always equal to the combined water and air resistance.

In Fig. 9, the water resistance is seen increasing to a maximum value and then decreasing again. Above is plotted the propeller thrust, from which the air resistance has already been deduced. The take-off time will now be determined. Graphical means are used, since the water resistance can hardly be calculated by analytical methods. An isosceles triangle is drawn, the speed of 9.81 m/s (32.2 ft./sec.) being its base and G/2 its height. This means that G/2 is accelerated to 9.81/2m/s in one second by the force of acceleration.

b = acceleration,

G = total weight,

P = force of acceleration = thrust minus resistance,

g = acceleration due to gravity.

Other triangles are now added, their sides being parallel to the sides of the first triangle and their apexes resting on the two curves. Owing to parallelism, the relation $G/g = P/b$ is maintained. The take-off time expressed in seconds is twice the number of the triangles. The take-off distance is the sum of the mean speeds for each second.* Systematic calculations of new designs can easily be made by this method and Madelung's diagram of water resistance, and a good general view of the subject thus be obtained.

Summary of Information Obtained

Figs. 9-12 afford a comprehensive view of the advantages and disadvantages of different wing loadings and low speeds on smooth water. The chosen example is based on three different take-off speeds, namely, 70, 85, and 100 km/h (43.5, 52.8, and 62 mi./hr.). Moreover, the total weight is increased by 10, 20, and 30%. The water resistance is computed from Fig. 6. Propeller thrust and air resistance remain unchanged.

The result of the take-off-time calculation is shown in Fig. 13. It appears that low take-off speeds result in shorter take-off times and considerably increased load limit.

*Dittmann, Different graphical methods for the determination of running time. "Journal for Railroad Development," June 15, 1924, p. 117.
Before I saw this article, Chief Engineer Schnell, Munich, called my attention to this method.

The equation of take-off speed

$$v = 4 \sqrt{\frac{G}{F}} \sqrt{\frac{1}{c_a}}$$

comprises the product $F\ c_{a\ max}$. Area and lift coefficient can be increased by using slotted wings. For equal span, the increase in the induced drag, with increasing lift coefficient and wing area, is linear. When adopting a slotted wing, owing to the great advantages resulting from high wing loading, its considerable induced drag should be taken into consideration and the span increased accordingly. Otherwise, the curve plotted in Fig. 1, parallel to the water-resistance curve, covers a larger speed field and produces a longer period of low excess of acceleration. This is often the case with monoplanes and biplanes without slotted wings. To be more accurate, the variation of the induced drag produced by the surface of the water should be taken into consideration, substantial differences being found in some cases.*

Water resistance is considerably increased by waves. The take-off speed with reference to the water is, however, considerably reduced by a head wind. Experience shows that the take-off time of seaworthy seaplanes, such as the Friedrichshafen F.49c, has a mean value at seaway 4 above or below the take-off time for calm weather and smooth water, according to whether the wind corresponds to the seaway or not. High waves without

*Wieselsberger, C. Wing Drag Near the Ground. "Zeitschrift für Flugtechnik und Motorluftschiffahrt," 1921, p. 145.

wind may prevent the best seaplane from taking off with full load. Furthermore, it was found that floats, as shown in Fig. 8, could not be used for alighting in seaway 4 at speeds exceeding 70 km/h (43.5 mi./hr.). At higher speeds, they are crushed in by the waves. A wider speed range, apparently up to 85 km/h (52.8 mi./hr.), is enabled by the floats shown in Fig. 54c (which are used in America and England).

The hull of every successful seaplane is provided with a step near the c.g. (Fig. 15). The water flow is thus interrupted and no suction exerted on the rear portion of the hull. If no step is provided, a strong suction effect is created at the stern and there is no, or a very small, decrease of resistance above the critical speed. Consequently, the water resistance can be overcome by hulls without steps only when they are very lightly loaded. It is far more difficult to overcome the high-water moments acting on a stepless hull with ordinary horizontail tail planes. In taking off, a stepless hull can be neither raised nor depressed. It has a considerably smaller hydroplaning angle than when there is a step. The step represents additional air resistance, increased weight and, just in the middle of the hull, a sudden change of section, which on many occasions has led to the rupture of floats and hulls at this point. Owing to these considerations, repeated attempts have been made to do without the step, but always with absolute failure. A seaplane could never take off without the step. The elevated point of application of the propeller thrust does not materially increase the water resistance.

The hull in Figure 15 has a step lying aft of the c.g. when taxying on the water after having exceeded the critical speed. Only a very small part of the step is submerged, but carries nevertheless up to 85% of the total weight of the seaplane. In this case, it is assumed that the hydrodynamic-lift resultant passes through the c.g. An additional water resistance is thus created with a value of approximately 1/5 of the total weight. This resistance acts at a certain distance from the line of thrust of the propeller and develops a nose-heavy moment which must be counteracted by the elevator. A downward force is thus produced and the seaplane becomes apparently heavier, the resistance and take-off time being increased correspondingly.

In Fig. 16 the step is located far behind the c.g., and the lift resultant passes aft of the c.g. There are two moments which make the seaplane nose-heavy: one by water resistance and propeller thrust, and the other by gravity and lift. Difficulties are often encountered in taking off, when the bottom of the hull is not efficient enough. In such cases the requisite downward pressure on the elevator may reach 10 to 15% of the total weight. The water resistance is thus considerably increased by the apparent increase in weight and the increased air resistance due to the full throw of the elevator in the propeller slip stream. Besides, in squally weather the eleavtor cannot always be deflected enough further to insure good maneuverability.

A hull with a too efficient bottom is easily thrust out of the water before the take-off speed is reached. Since sufficient lift is not reached at that moment, the seaplane falls heavily back on the water. The seaplane may also happen to be stalled just when, owing to the position of the step, the elevator is already fully deflected and a serious accident, such as side-slipping, may then result. By such leaps considerable stresses are exerted on the hull. The speed at which they begin can be determined by tank tests. For well-designed seaplanes, they do not occur before 90% of the take-off speed is reached. English flying boats jumped even at 50% of the take-off speed. The English Felixstowe "Fury" (Fig. 25) with five 250 HP. Rolls-Royce engines, was completely destroyed by such leaps. In this case, tank tests should have been made before the construction of the seaplane and not after the crash. This tendency can often be avoided by a slight displacement of the c.g. or by an additional moment sometimes forward and sometimes backward. If no improvement is thus obtained, the efficiency of the bottom must be reduced by lowering the step or shifting it forward, or else by reducing its width. Shifting the step under or in front of the c.g. means a reduction of the efficient part of the bottom and an increase of water resistance and spray, thus necessitating increased engine power.

Under normal conditions a tail-heavy moment is developed by the water, so that, in order to obtain equilibrium, the step should not be located too far forward. Moreover, there are certain types (such as the German standard float, with a trimming step far aft of the c.g.), which automatically assume larger angles at the critical speed. The tail-heavy moment before and while rising on the step is due to a bow wave which the hull pushes in front of itself. If this wave is cut by an appropriate bow (which usually reduces the resistance), the step must be shifted forward. In general, the sharper the V-bottom, the smaller the tail-heavy moment.

Formerly, air vents were often arranged behind the step to facilitate the separation of the water behind the step. On certain hulls (usually not very well designed) an extremely small, scarcely measurable reduction of resistance was effected. It is so small, however, that this means was finally abandoned. The air vents, necessarily of light construction, were a constant source of leakage.

The cross section of the hull or float behind the step must be such as to avoid close contact with the water and the production of suction effects. To this end, the outer part of the step is frequently raised above the inner part, or the bulkheads behind the step are laterally higher than in front. Experience has shown that, when the sections behind the main step are oval or deeply curved at the bottom, the water clings closely to the hull and produces a strong suction effect. It is advisable to provide any oval hull section with two sharp lateral edges or chines at the bottom.

There are both single-stepped and two-stepped hulls. The second step has a low water resistance and produces a stabilizing effect during the take-off. In this case, the hull runs on both steps and no, or a very small, longitudinal rocking motion is produced. In the case of a single step, the seaplane is balanced on the main step by means of the elevator. Head waves are more easily overcome by pulling the elevator control back in advance. To produce the desired effect, the second step must be some distance behind the first step. If it is too near the first step, no satisfactory stabilizing effect is produced, because its water resistance is too small. All these points are subject to various valuations. Therefore, there are still many contradictory opinions regarding the rear step.

Conditions are different with reference to a third step. The bottom, the position and the height of the main step should be so designed as to insure a smooth separation of the flow. Hulls which did not satisfy these conditions were formerly provided with a third step between the two others. This was never found, however, to be more than a slight improvement of a bad design. It is better to go straight to the bottom of the question and arrange the lines correctly. Hulls or floats with more than two steps became obsolete five or six years ago. For the last six or eight years, twin floats have been built with only one step.

The angle formed by the front and rear parts of the bottom of the hull greatly affects both the take-off and alighting. If this angle is too small, the wings cannot be given the required angle of attack to produce great lift. This is equivalent to increasing the take-off speed. Besides, the pilot will encounter difficulties in overcoming head waves with a single-stepped hull. Alighting is also rendered more difficult by the low position of the tail. In good designs, this angle is 10 to 15 degrees.

The cross section of the hull, as seen from the front, greatly affects its characteristics. In this connection, a few fiducial lines have likewise been worked out. The shock of alighting on water is smallest when there is a sharp V-bottom, but the water resistance and the formation of spray are then the greatest. This point is less important for flying boats exceeding 10 metric tons in weight, since their take-off speed is small in comparison with their size. In this case, the reserve power is large enough to overcome high water resistance. Consequently, for such boats, preference is given to a sharp V-bottom in order to reduce the impact on the water. The contrary method is applied to light flying boats, in order to insure operation with a small excess of power. In this case, a stronger impact on the water is taken into the bargain.

Every V-bottom produces spray. The sharper the V, the more the spray. A sheet of water rises on each side and wets the wings, the hull and the propeller. The spray is reduced by bending the upper part down, as is done on the Linton-Hope hulls (Figs. 34, 36, 40, 42, 50 and 65), by fitting a strip beneath the outer edge of the chine, thus reducing the depth of immersion, and by increasing the angle of attack of the hull and by giving a suitable shape to the bow. The cross section should be hollow and V-shaped with a flat, wide ground plan and approximately horizontal lateral and bottom surfaces to ride the water. The chines, or the more or less horizontal bottom surfaces, must be gradually raised toward the front. Little or no reduction of spray is produced by longitudinal beams beneath the bottom.

The best shape of hulls and floats can be developed by tank tests or by building a sufficient number of models. The same results are obtained by both methods. The second method is more expensive and considerably slower. Regardless of the danger involved, this method was worked out during the war at Felixstowe, England, by Colonel J. C. Porte, officer of the British naval air service, who had no engineering training. The resulting sacrifices of human life could have been avoided by tank tests. These experiments were subsequently described by Rennie in an apologetic note.*

*Rennie, J. D. - Some Notes on the Design, Construction and Operation of Flying Boats. "The Journal of the Royal Aeronautical Society," 1923, p. 123.

Owing to its great importance, a brief description* of the hulls tested and evolved at Felixstowe, follows:

"The first experiments were taken in hand early in 1915, when no engines of high power were available, hence the chief difficulty met with was the problem of taking off with a reasonable load. Thus the early experiments were made with the object of developing hydroplaning efficiency; such questions as safe landing, seaworthiness, stability, etc., were more or less neglected until more powerful engines became available. The first hull tested was a modified Curtiss "America" flying boat (Fig. 17): weight, light, 3100 lb.; fully loaded, 4500 lb.; horsepower, 160; length of hull, 30 ft.; single step, projecting fin forward, ending at step, which was under the c.g. Fore and aft angle between the underside of the tail and planing surface of the ship was 10 degrees.

At high speeds all single-step hulls balance on the step, and trim depends upon the angle of the tail portion which, to avoid water drag, should be held up during the acceleration period. The original tail plane was lifting, which was excellent from this point of view, and as much load as could be flown with could be taken off the water. To improve the stability in flight, especially trim engine on and off, the tail was made negative. In smooth water there did not seem to be any appreciable loss in hydroplaning efficiency, but in rough weather, owing to the lack of buoyancy forward, she was very wet.

*Extract from Rennie's paper on Flying Boats (See footnote, p.20).

A new hull (Fig. 18) was built, in which the fins were narrower, and carried further aft, the underside of tail rounded, and of lighter construction. This hull proved to be inferior to Fig. 17, owing to the rounded underside of the tail portion, which caused increased suction, making it very difficult to lift out of the water in calm weather. With the different type of construction adopted there was a saving of about 300 pounds, but it was considerably weaker than the previous hull, and failed after several landings.

The next hull (Fig. 19) was similar to Fig. 17, but the tail portion was 2 ft. longer, and fore and aft angle reduced to 7 degrees. Owing to the reduction of this angle, it was not possible to trim back to the same angle as with Fig. 17, resulting in a higher "taking off" speed.

The chief lesson to be learned from these hulls was, from the point of view of ability to hydroplane and low taking off speed, the tail portion should be flat-bottomed to reduce suction, and fore and aft angle should be large to obtain the necessary trim.

It was now decided to tackle the problem of easy landing conditions, and increased strength without sacrifice of planing efficiency.

As most landing breakages in those days occurred at the step, the next experiment was to find if a step was necessary. A complete new bottom was built on the previous hull, with no step, but steeper "Vee" bottom, and tail well swept up (Fig. 20). The engine power available was not sufficient to take off. A step was then added 5 ft. behind the c.g., when 4200 pounds were taken off. Landing was exceptionally easy owing to the large fore and aft angle. The deeper "Vee" resulted in little or no shock, with either a normal or nearly stalled landing. Owing to the step being so far aft of the c.g., the hull ran at a small angle and a large moment was necessary to trim back to take off. To relieve the pilot of this load, the step was shifted 3 ft. forward.

The next hull was called the Porte I (Fig. 21), and was the prototype of all the "F" boats. An entirely different type of construction was used, which will be shown later. The hull was built at Felixstowe, and carried the same "Curtiss" superstructure as before. Originally a single step, below the rear spar, was fitted; hull 2 ft. longer in the nose and tail than Fig. 19, being 36 ft. over-all; fore and aft angle 18 degrees, tail portion 7 in. higher than on Fig. 20; fins were carried well aft of the step and swept back into the hull; "Vee" bottom, as in Fig. 20; bows fuller with a distinct flare on the first 3 ft.

Difficulty was experienced in taking off owing to tail drag. A second step was therefore fitted 7½ ft. from the stern. It was now possible to take off, but with less load than earlier hull. Finally, a third step was added intermediate between the main and aft steps. This brought load capacity up to that of the earlier hulls. This hull was in many respects far superior to any hull tested previously owing to the improved form of bows; cockpits were dry, landing shocks were reduced to a minimum, and behavior generally - landing and getting off - was excellent.

It was now decided to experiment with larger hulls, and to begin with, a large Curtiss "America" was obtained (Fig. 22), particulars of which are as follows: Total weight, 8700 lb.; twin 160 HP. Curtiss engines; hull 40 ft. long, 11 ft. maximum beam; fore and aft angle, $7\frac{1}{2}$ degrees. With this load there was not sufficient power to take off. 240 HP. Rolls-Royce engines were then fitted. Load taken off with difficulty, principally due to the lack of buoyancy forward. A most marked hump speed, about 18 knots, was noticed. At a later date, when more powerful engines became available, these boats did some quite good work, but hulls were weak structurally. As the Porte I (Fig. 21) hull was much superior to Fig. 22, it was decided to design and build a new hull on the same lines to take the "America" superstructure, and known as the Porte II (Fig. 23). Particulars: weight loaded, 16,500 lb.; hull, 56 ft. 10 in.; and fore and aft angle, 20 degrees; bows 2 ft. longer than Fig. 22; two steps, one under rear spar, and the other 7 ft. aft of spar, proved a much superior boat. Hump speed less marked, accelerated evenly and rapidly to the taking off speed. Loading capacity increased. General seaworthiness greatly improved, gain in buoyancy, and structural strength without increase in weight.

Porte Baby (Fig. 24).- The building of this large experimental flying boat was carried out during the same period as the experimental modifications to the Curtiss "America" hulls were in hand, and while the experience gained from them was incorporated, it was not possible to take advantage of the results from the Porte I. Experience with these hulls confirmed the results obtained with the "America" hulls. Particulars: Weight, loaded, 16,500 lb.; hull, 56 ft. 10 in. long; beam at step, 14 ft.; width of body, 7 ft.; fitted with three 250 Rolls-Royce engines; wing as tractors, and center a pusher.

Trials showed the length of forebody was not sufficient to prevent wallowing in a following sea. Bows were lengthened 3 ft., which enormously improved water performance. Air pipes fitted to the step were found to be unnecessary.

Considering the low power and the use of stranded cables throughout, the air performance was quite good. Top speed, 68 knots; climb up to 3000 ft., about 150 ft. per minute. Time to unstick with full load, about 35 seconds.

It was decided not to proceed further with the development of the type, as the water performance was much inferior to the Porte II, and type of hull construction, weak.

Taking into consideration water performance and hull construction, the most promising type to develop was obviously the Porte II. This led to types known as the F.2A, F.3, and F.5.

In the F.3 and F.5 types, the hull was lengthened 3 ft., otherwise the lines were essentially the same as those of the Porte II. Increased horsepower and improved detail and aerodynamic design led progressively to greater load capacity and air performance. These types were put into production and used extensively during the late war.

From the experience gained with these latter types, it was decided to construct a still larger boat. The P.S.B., or Porte Super Baby, officially known as the Felixstowe Fury, was the result. Fig. 25 shows profile, plan, and body sections in detail. It was originally designed for 24,000 lb. total weight, and to be fitted with three 600 HP. Rolls-Royce Condor engines. As these engines did not become available, five Eagle VIII's had to be used, which led to a decided drop in air performance.

From every point of view, the boat was the best design turned out at Felixstowe. It was found that the normal load could be increased to 28,000 lb., under which loading, seaworthiness, ease of taking off and launching were superior to that of the previous F-boats. Loading tests were continued up to 33,000 lb., at which load Colonel Porte took her off in Harwich Harbor. Landing under all loads was without perceptible shock.

The extraordinary behavior of the hull in rough seas was due mainly to the buoyancy of the hull and the lines adopted. With a load of 28,000 lb., the chine at main step was not submerged. Under all conditions, the propellers, cockpit and tail plane were clear of water thrown up. From this point of view it was found that the bow sections could be improved considerably. These were too blunt, resulting in unnecessary pounding when getting off or landing in a rough sea, or at moorings. It was decided in any future designs to drop the keel profile forward, keeping everything else the same, thus obtaining a finer entry, without loss of buoyancy forward. The net result of all these experiments is that the lines and dimensions (Fig. 25) of a successful flying boat hull for a given displacement have been evolved. It now remains to show how the various features in the design contribute toward the fulfillment of the requirements laid down above, and to indicate where, if at all, these differ from what might be deduced from tank tests.

The experience gained required several months' work, whereas the same results would have been obtained in a few weeks by model tests. When testing short-bowed models, the cockpit openings were deluged with spray to a considerable extent (owing to the conditions of friction). The fact that a step is located too far aft is more easily revealed by a model, which is not subject to the influence of a wrong position of the c.g., or of the elevator. On the actual hull or float, the faults become apparent by the difference of various values, but they are revealed clearly by the model alone. The tendency to leap, which is a serious defect of hulls and floats, is entirely passed over by Rennie.

English Tank Tests

Tank tests of hulls and floats have been made since 1913 by Baker* in the William Froude tank of the National Physical Laboratory, the method and extent varying according to the requirements of practice. We have selected from these a number of measurements having permanent value.

The measurement of the impact of a float on water for different V-bottoms is of special interest.** Among the three shapes shown in Fig. 26, 377 A resembles the usual German standard float, 377 B, the float of the American Navy, and 377 C, the English P-hulls. The simplification of the shape above water is of no importance. The models were dropped on the water with increasing speed. With immersion, the dropping speed decreases to zero and the float is then directed upward. The deeply submerged float rocks slightly about the position of equilibrium and then comes to rest. The upward velocity is small, but the acceleration and the retardation are considerable. The above considerations lead to the following conclusions:

1. Low alighting speed, or increased size of the hull for the same alighting speed, always results in reduced impact.

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*Baker, G. S. - Ten Years' Testing of Model Seaplanes. "The Journal of the Royal Aeronautical Society," 1923, p. 224.

**Bottomley, H. G. - The Impact of a Model Seaplane Float on Water. British Advisory Committee for Aeronautics Reports and Memoranda No. 583, March, 1919.

2. Increase of alighting speed may produce disastrous effects on floats without V-bottom, but is tolerable on V-bottom types (Fig. 27).

3. Under similar conditions the impact is smallest when the rear portion first comes into contact with the water (Fig. 28).

4. The shape 377 B produces, with a few exceptions, the smallest impact. Shape 377 C is nearly identical with it.

The lines of the N.4 Titania and the N.4 Atalanta flying-boat hulls are shown in Figs. 29-31.* Tank tests were made only after the Titania was already under construction. It was first intended to omit the central portion of the step and leave only the lateral portions. Owing to excessive water resistance, the step was subsequently extended over the whole width and even the lateral portions were enlarged (Fig. 32). When the step is too small, the resistance is typically similar to the case when there is no step at all. It does not decrease sufficiently beyond the critical speed. The Titania was found faultless. Notwithstanding the sharp V-bottom, the resistance is small, owing to low loading of the rather large hulls. (For a continuation of this article, see Part II: Technical Memorandum No. 427.)

*Baker, G. S. and Keary, E. M. - Experiments with Models of Flying Boat Hulls. British Advisory Committee for Aeronautics Reports and Memoranda No. 472, Sept., 1918.

Translation by W. L. Koporindé, Paris Office, National Advisory Committee for Aeronautics.

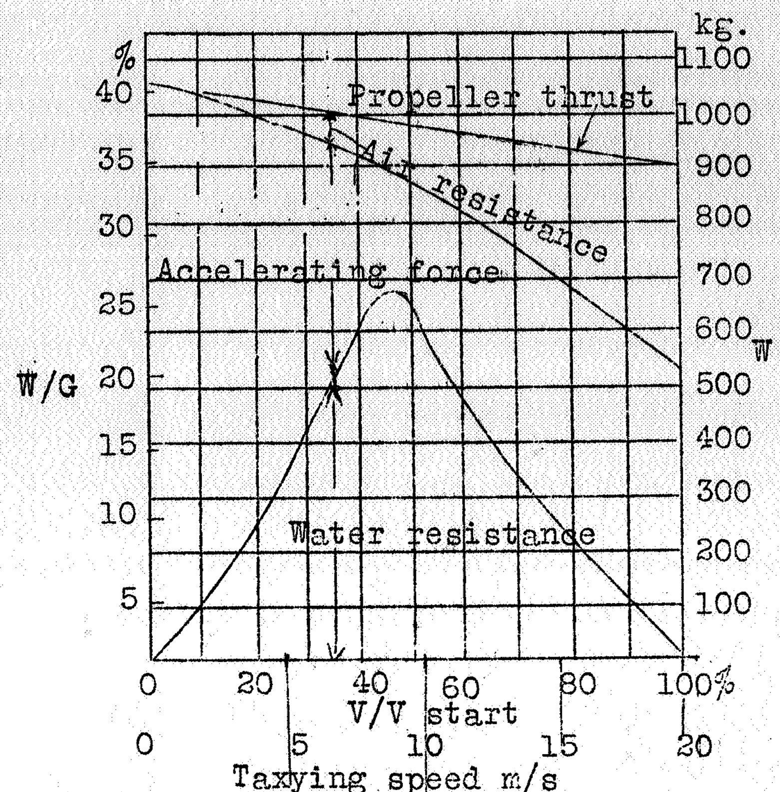

Fig.1 Diagram of water resistance.

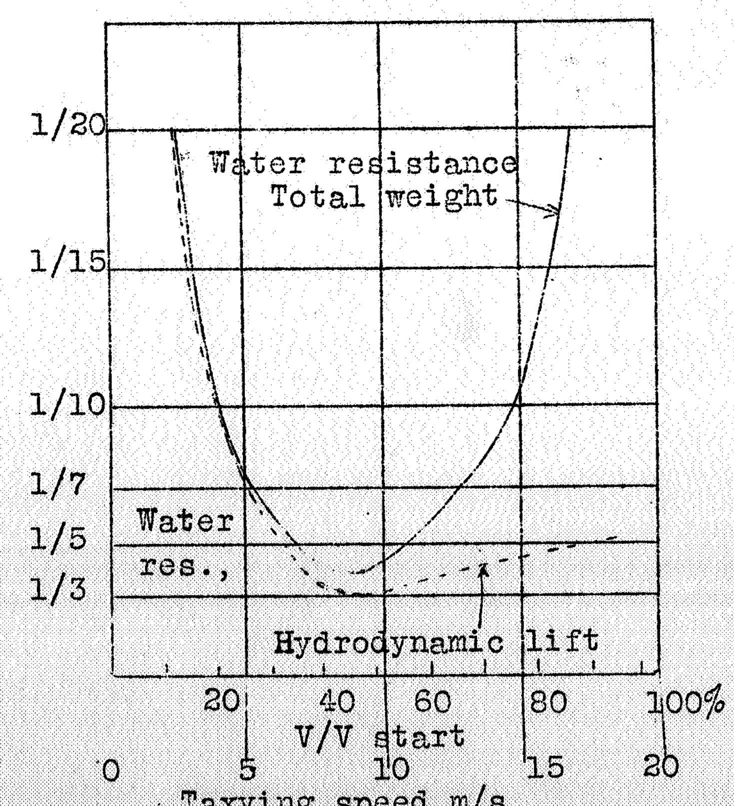

Fig.2 Diagram of water resistance. Numbers from Fig.1 in a different relation.

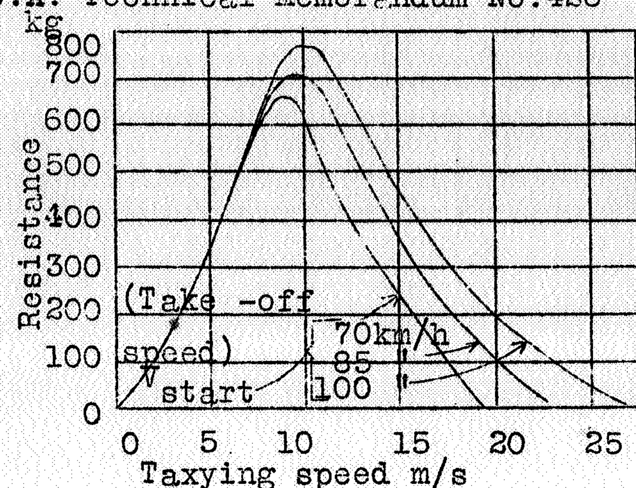

Fig.3 Water resistance at different take-off speeds.

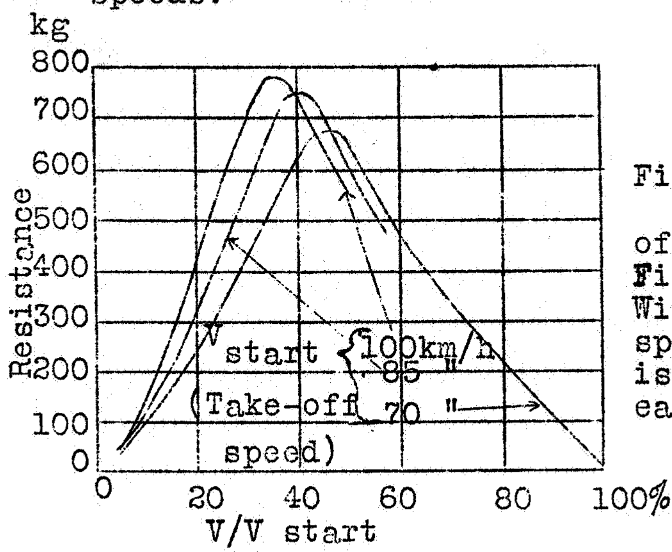

Fig.4 Water resistance at different take-off speeds. Numbers from Fig.3. Other relation. With increasing take-off speed, the critical speed is reached relatively earlier.

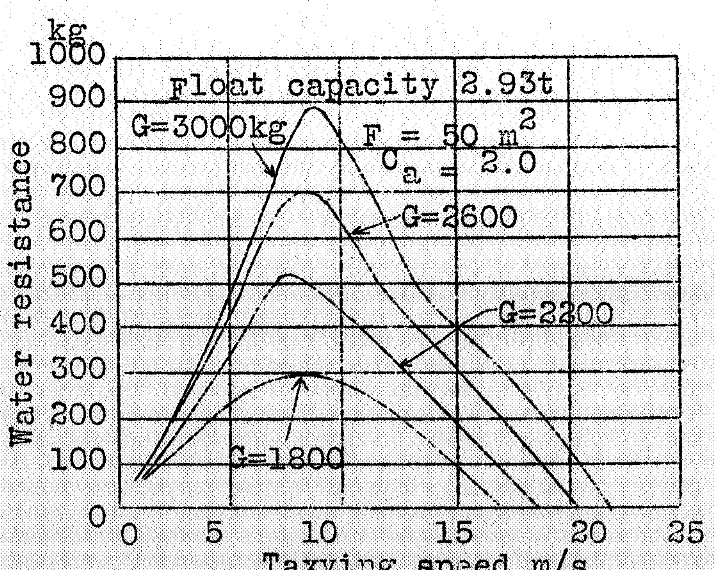

Fig.5 Water resistance of a twin-float seaplane for different total loads. In all cases the float surface remains unchanged.

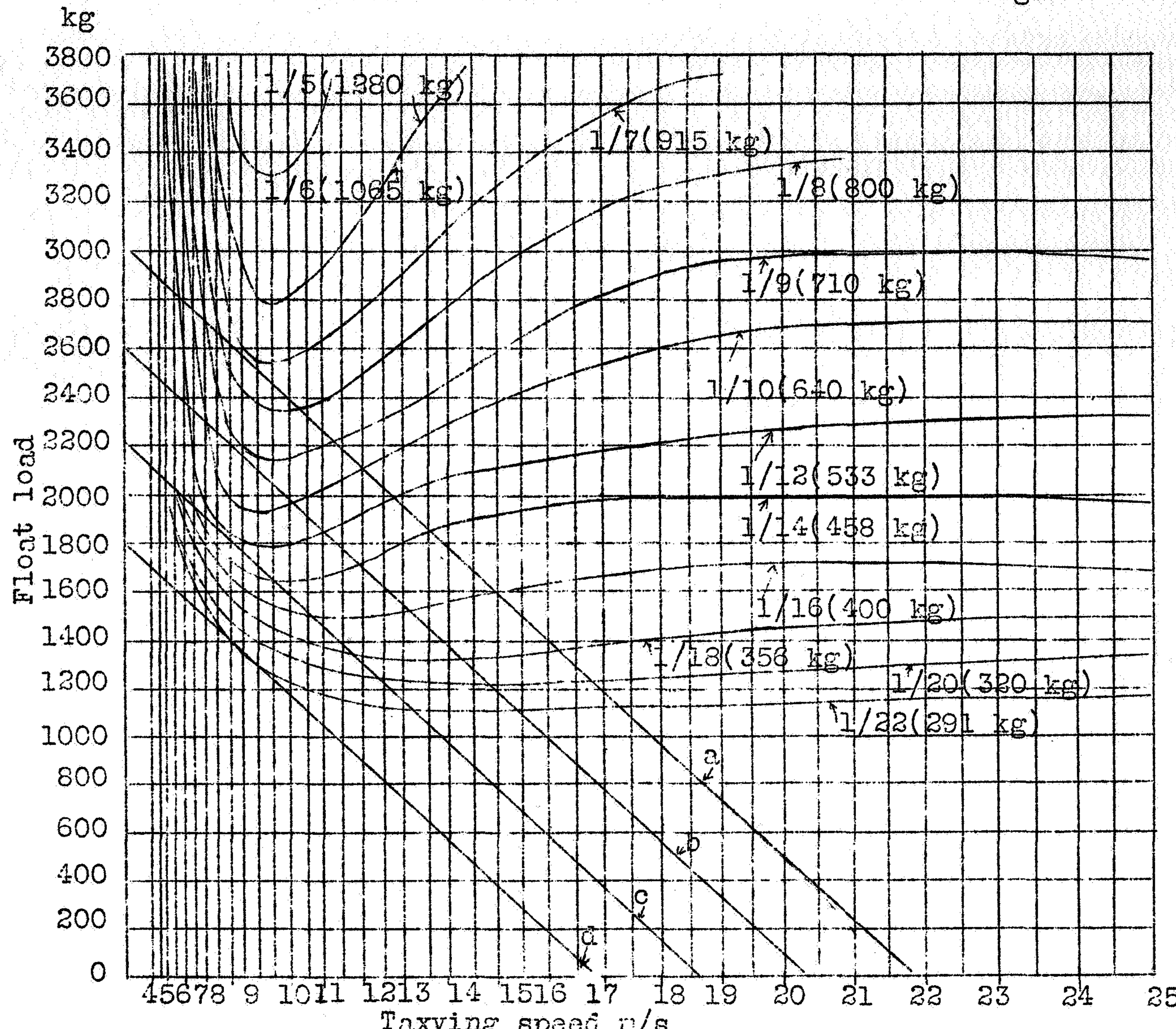

Fig.6 Madelung's diagram of water resistance for conditions in Fig.5. Reference number 6.4 tons total capacity. In case the resistance of floats or hulls in their original form is too high, the submerged part can be increased and the emergent part of the body reduced, thereby referring the datum to an invariable line. In this case it is assumed that the float has been increased to 3.2 metric tons according to Fig.8 and then reduced to 2.93 tons by removing a parallel strip of the deck and reducing the height. The submerged part remain unchanged, but their resistance is reduced by increasing their width.

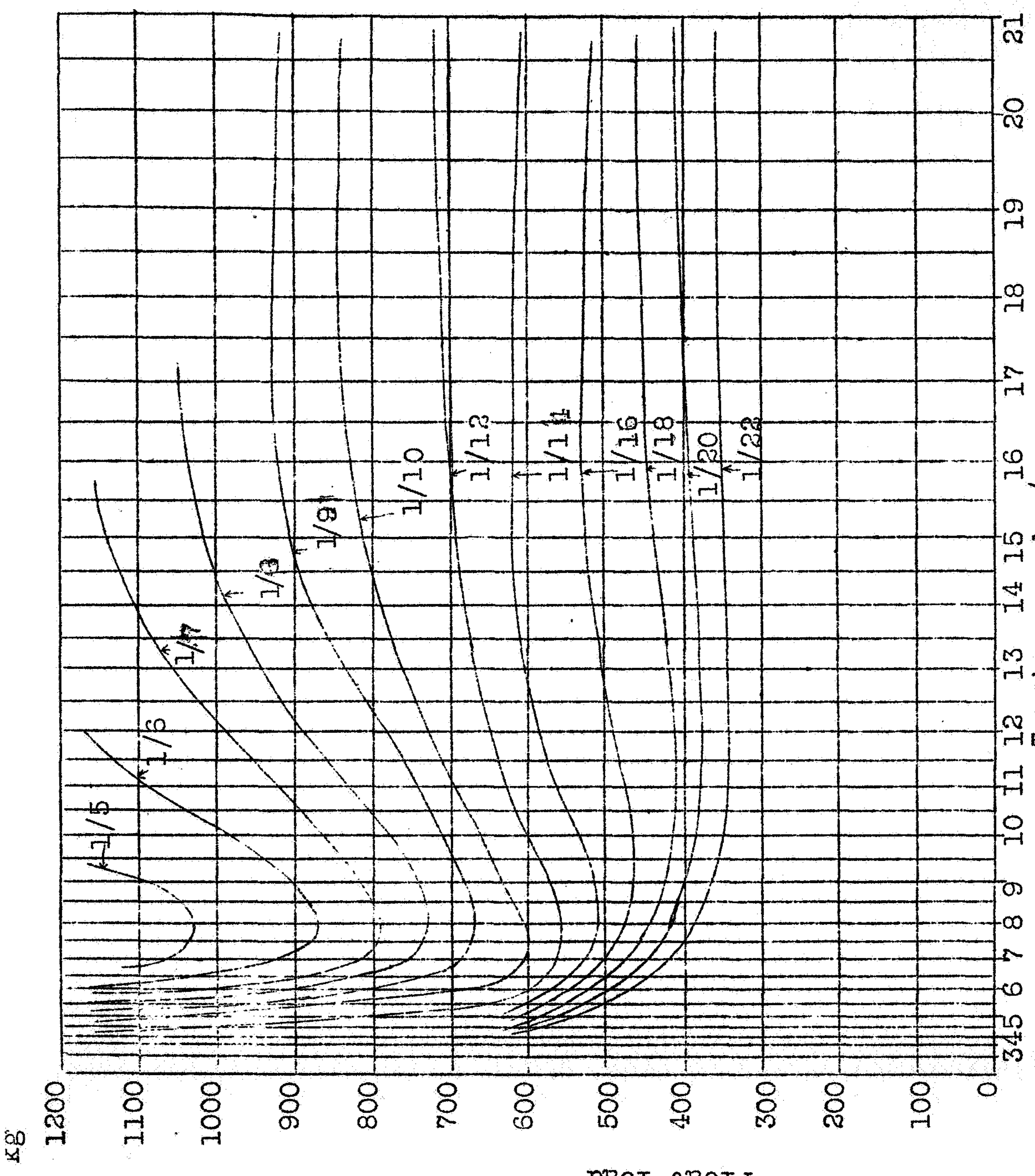

Fig.7 Madelung's diagram of water resistance for normal twin-floats. Resistance is given as a fraction of 2 tons.

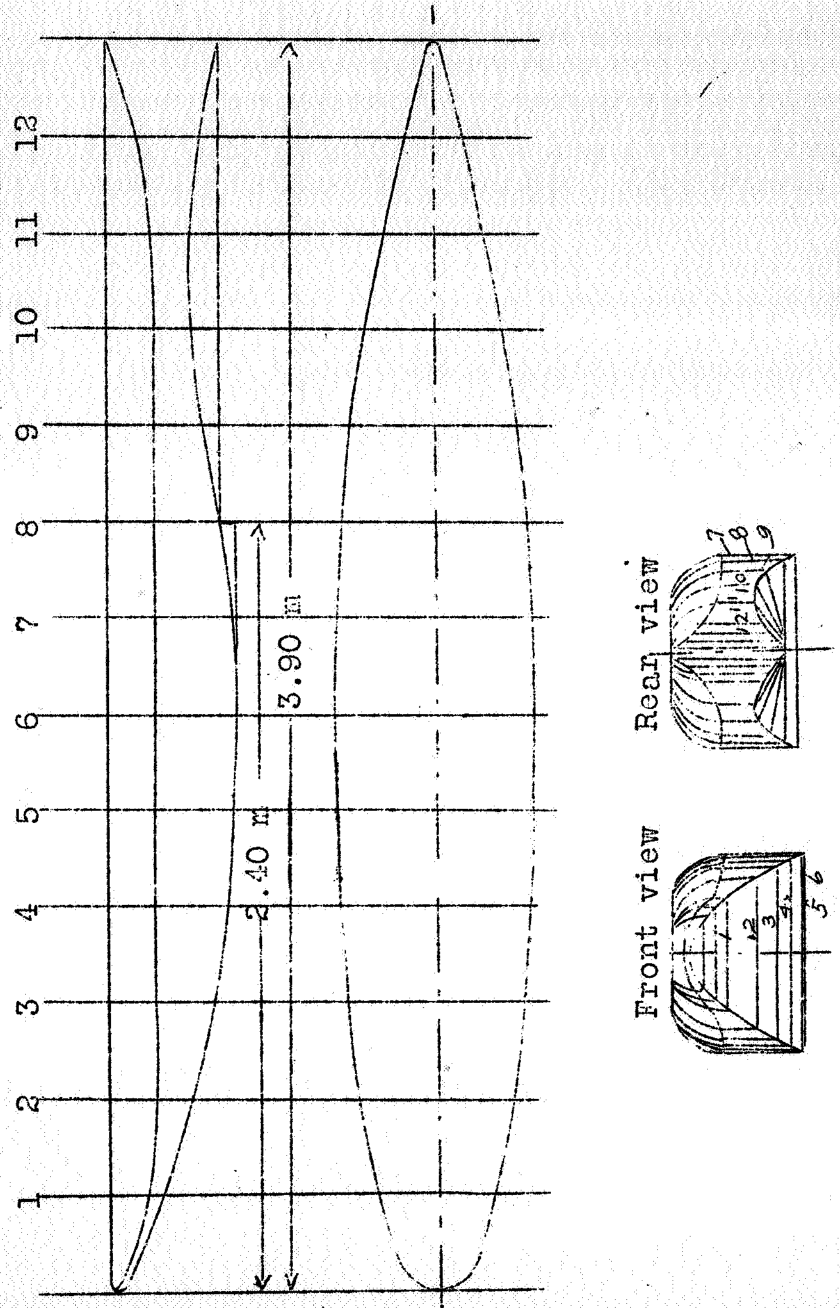

Fig.8 Lines of the float to which the water resistances of Fig.7 refer. The dimensions correspond to a capacity of (540 kg) for each float. Dimensions for 1 ton capacity

Overall length	4.79 m	Overall height	0.49 m
Length to step	2.94 m	Height of step	0.064 m
Overall width	0.75 m	Distance between floats	1.96 m

Increasing distance between floats does not practically change the resistance.

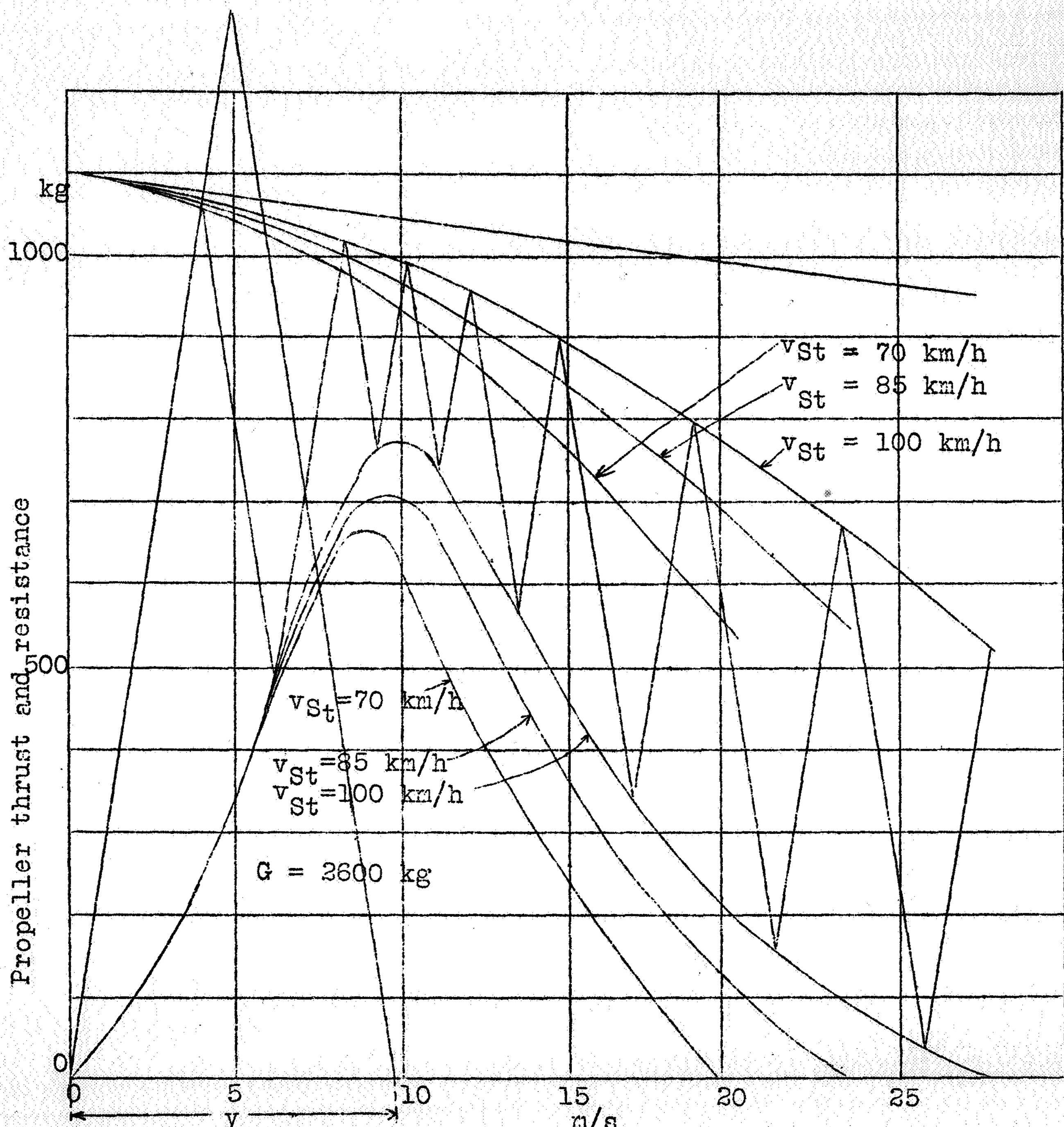

Fig.9 Calculation of take-off time. Result: 16 seconds.

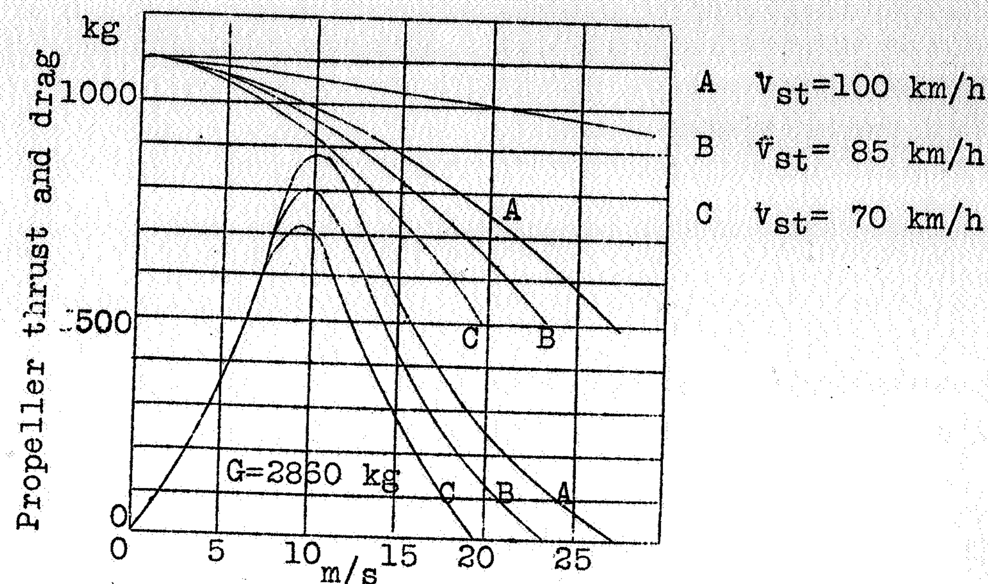

Fig.10 Calculation of take-off time for a total weight of 2.6 tons

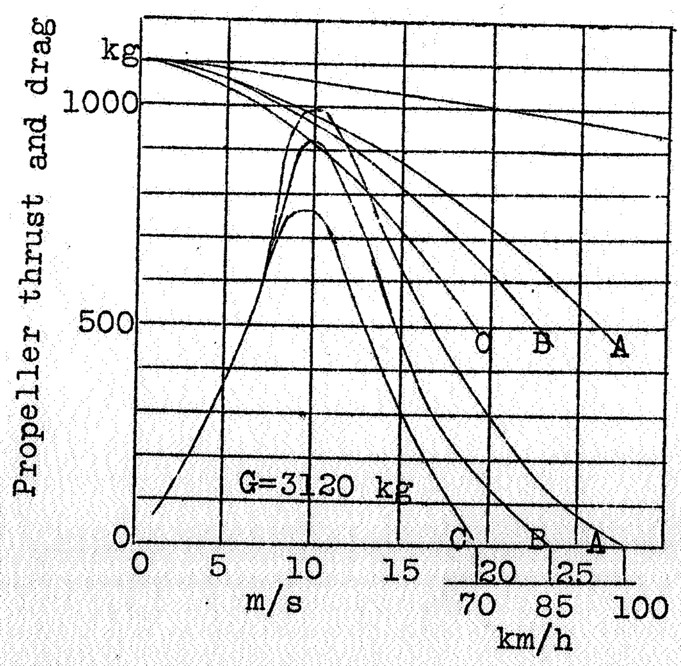

Fig.11 Calculation of take-off time.

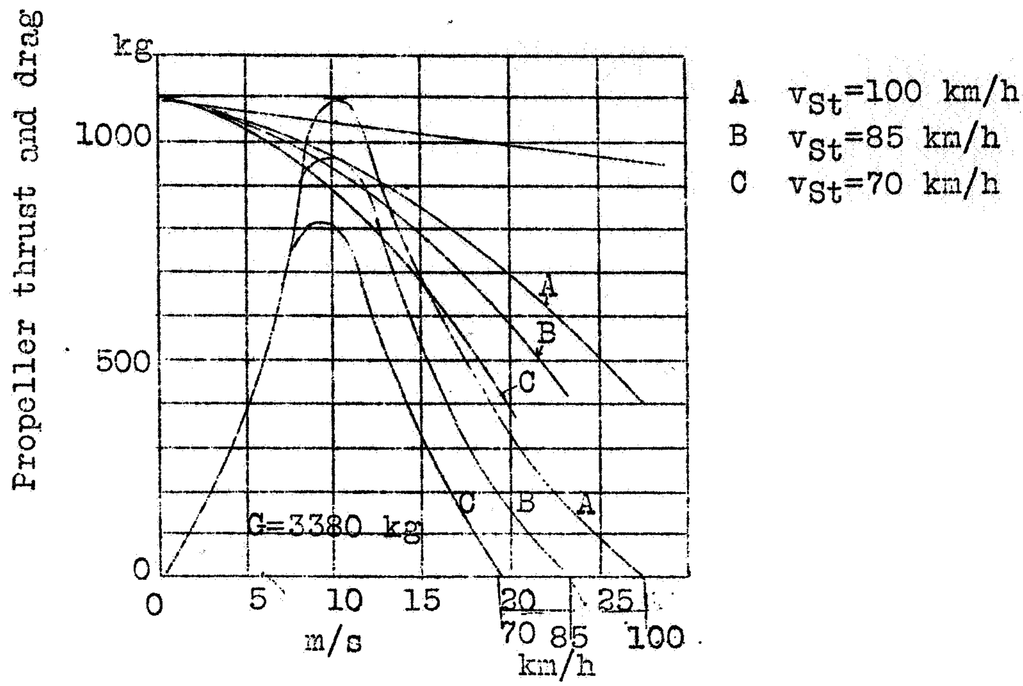

Fig.12 Calculation of take-off time.

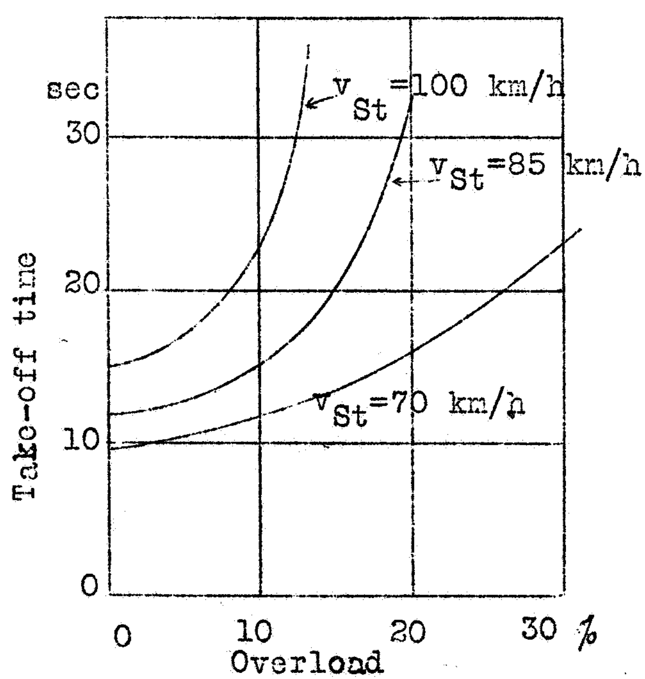

Fig.13 Influence of overload on take-off time at different take-off speeds.

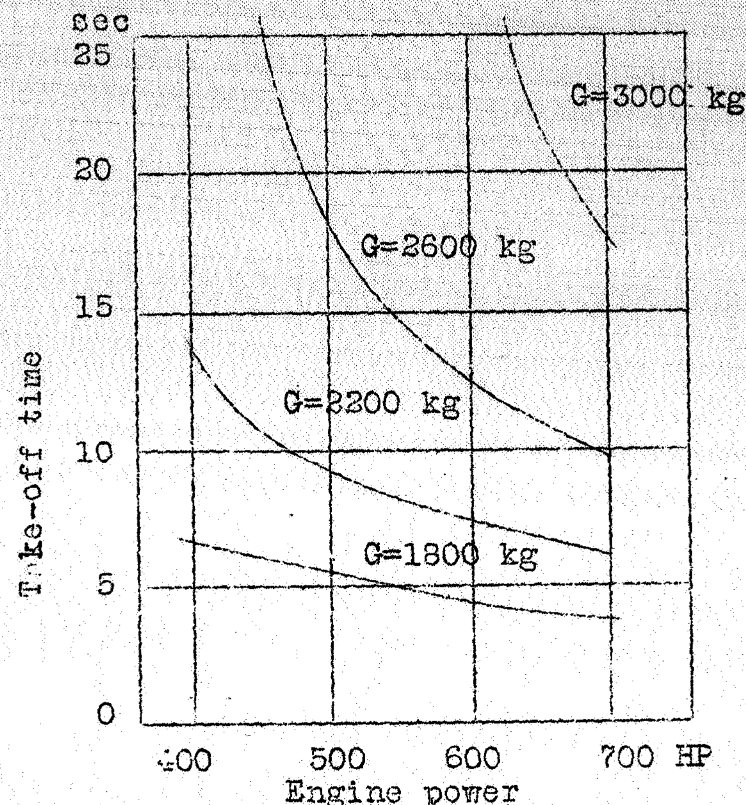

Fig.14 Take-off time in function of engine power.

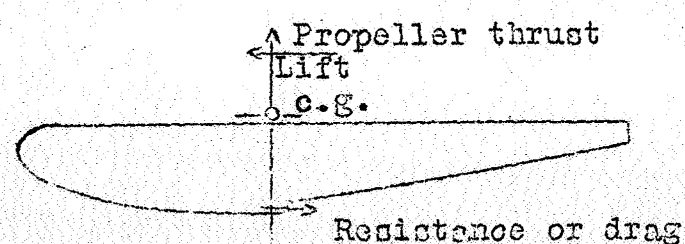

Fig.15 Force acting on a hull with step near the c.g.

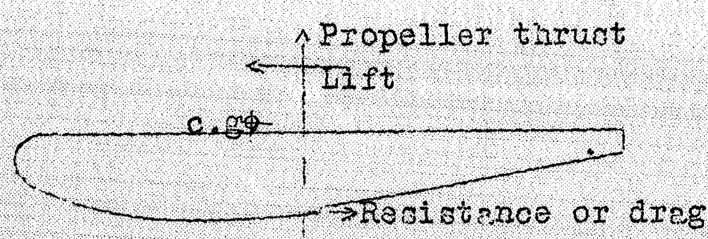

Fig.16 Flying boat with step located far aft of the c.g.

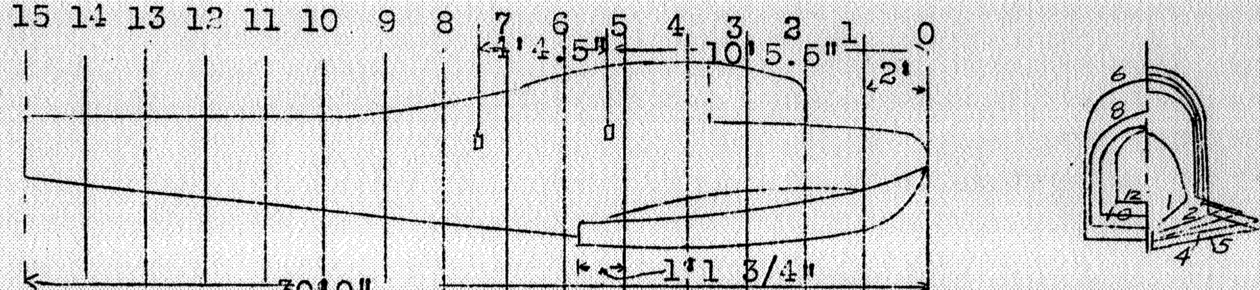

Fig.17 Lines of the Curtiss America 1915. Bow too short.

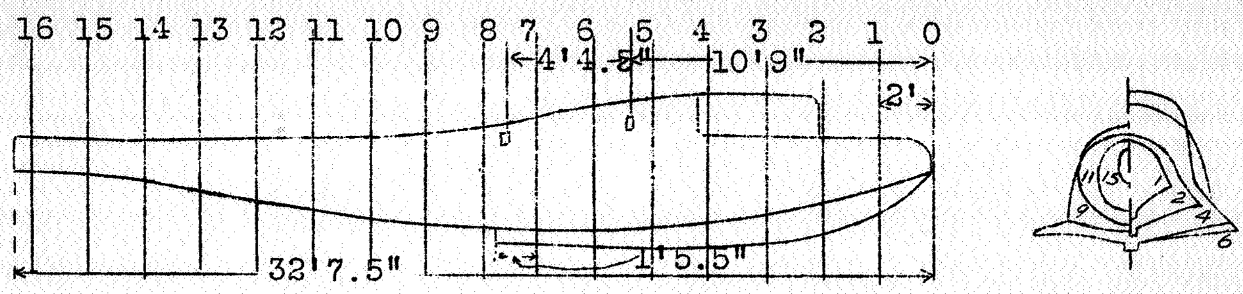

Fig.18 Lines of an experimental hull. Rounded rear portion produces unnecessary water suction and resistance.

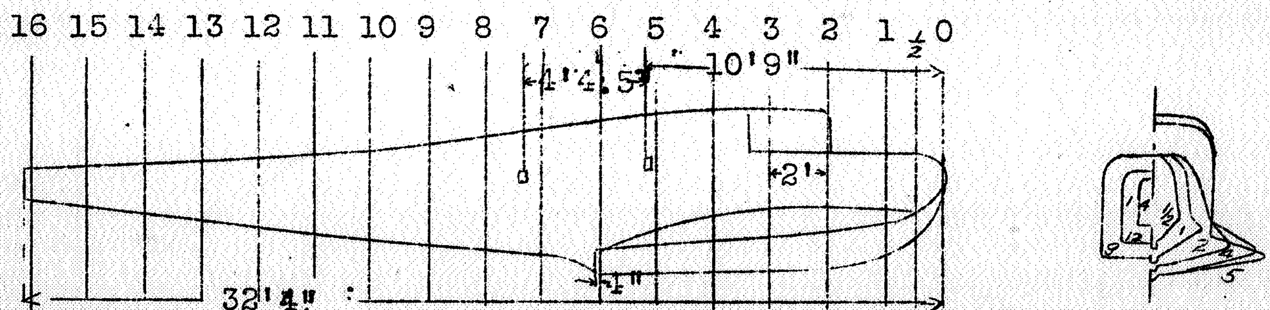

Fig.19 Lines of an experimental hull. Angle between front and rear portion too small.

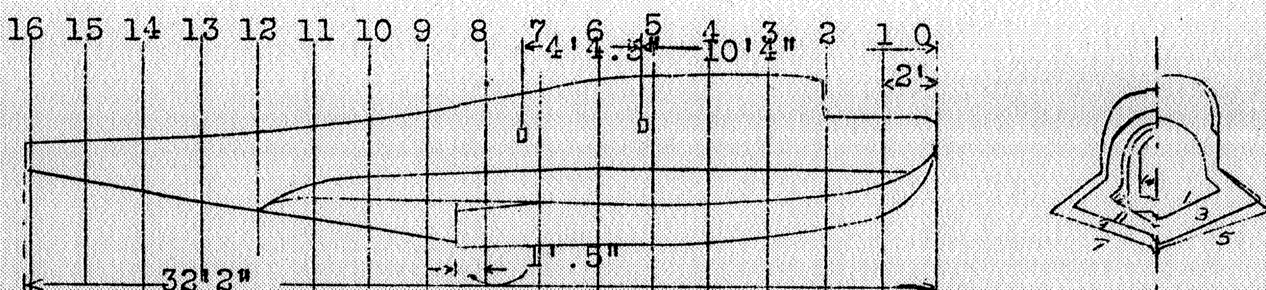

Fig.20 Lines of an experimental hull. Take-off attempts without step failed. Existing step too far aft.

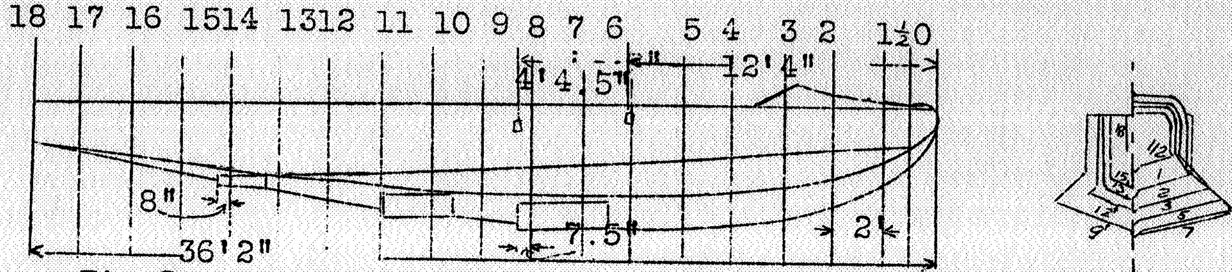

Fig.21 Lines of a good experimental hull. Subsequently it was found possible to get along with two steps.

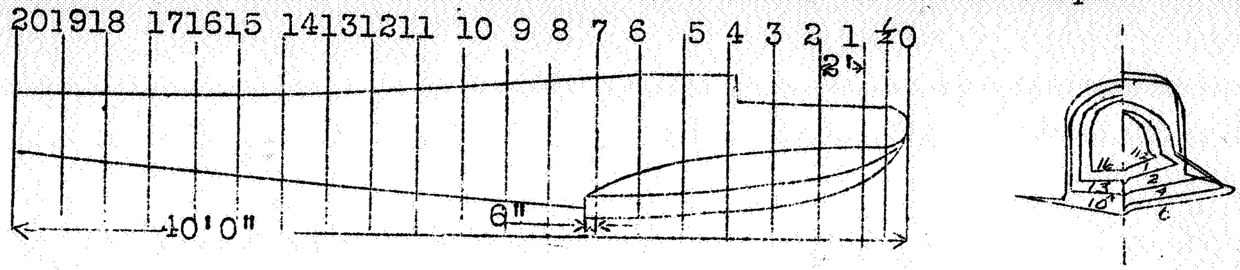

Fig.22 Lines of a larger experimental hull with too short bow.

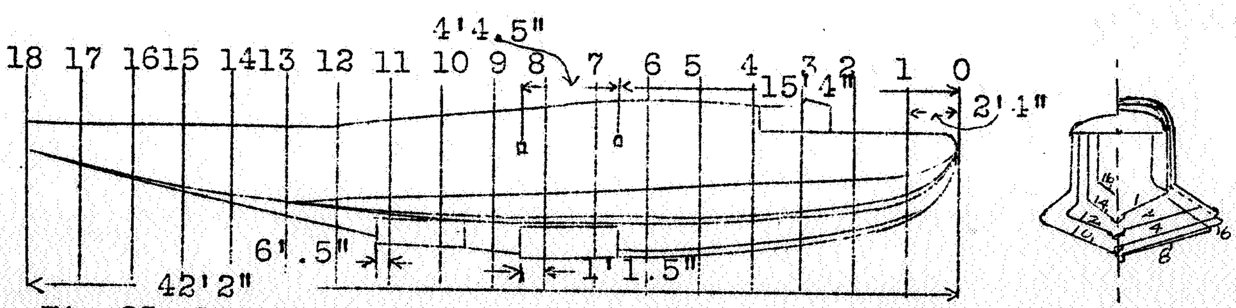

Fig.23 Lines of a larger successful experimental hull. Now the second step is located further aft.

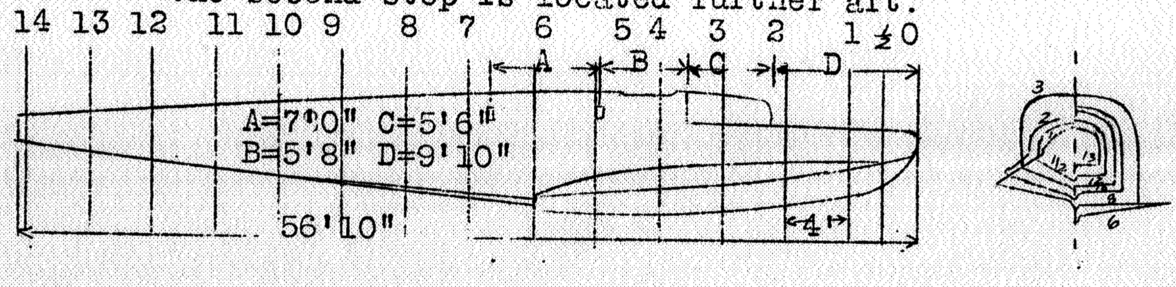

Fig.24 Lines of a larger experimental hull. The bow had to be extended 1 meter.

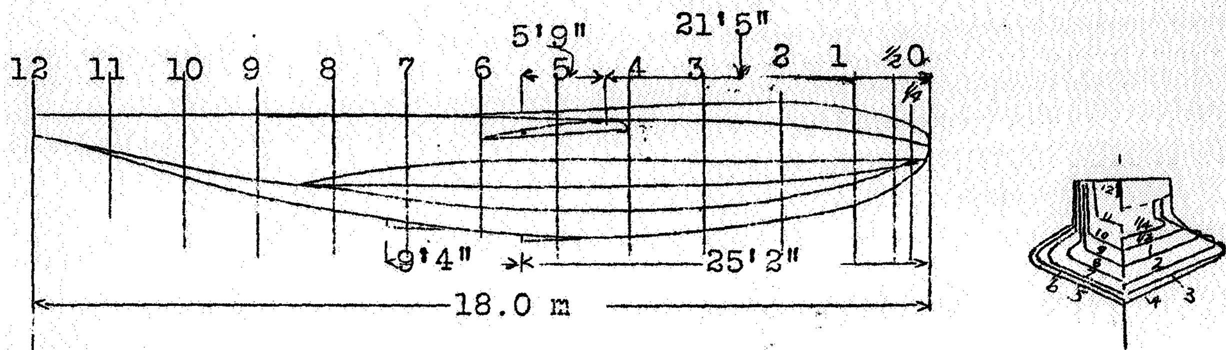

Fig.25 Lines of the Felixstone "Fury". Better results might have been obtained with a sharper V-bottom bow. Inclined to leap before reaching take-off speed, owing to very large and efficient bottom. Trimmed aft and leaped with insufficient lift, being subsequently crushed.

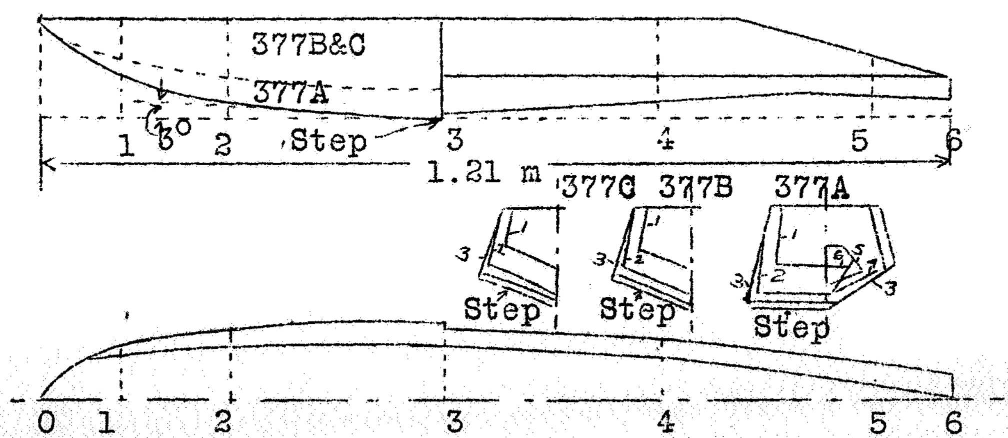

Fig.26 Lines of the three floats subjected to alighting impact tests.

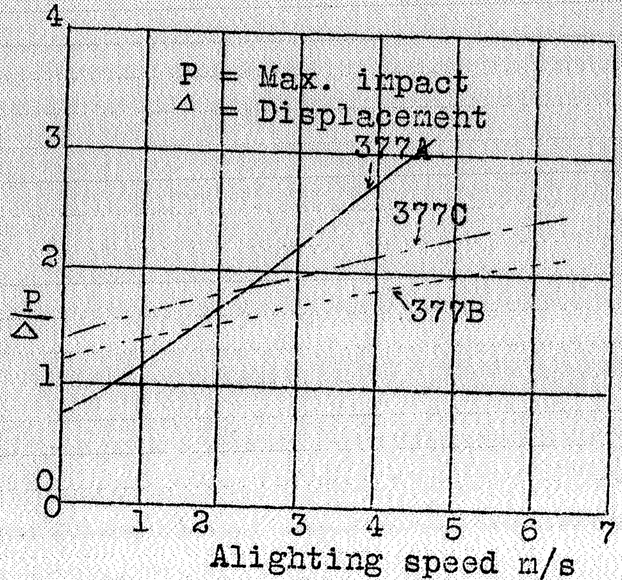

Fig.27 Alighting impact at different horizontal speeds. Vertical speed = 0.425 m/sec. The numbers refer to the model.

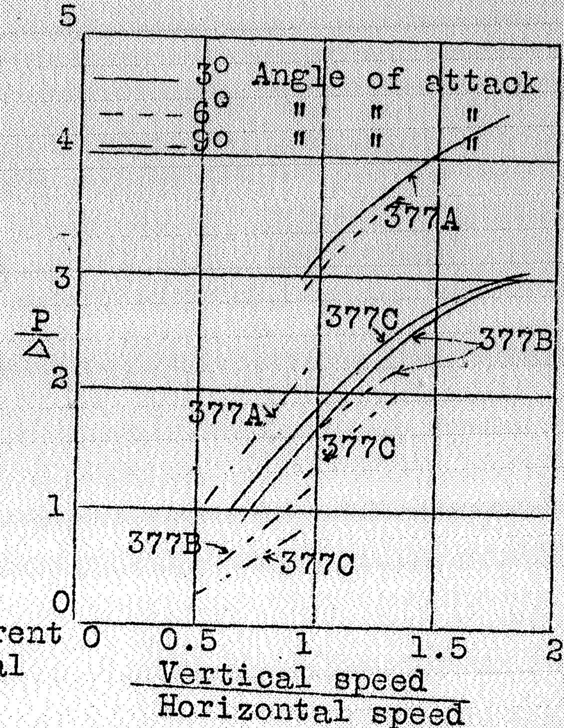

Fig.28 Alighting impact for different take-off and alighting angles. The numbers refer to the model.

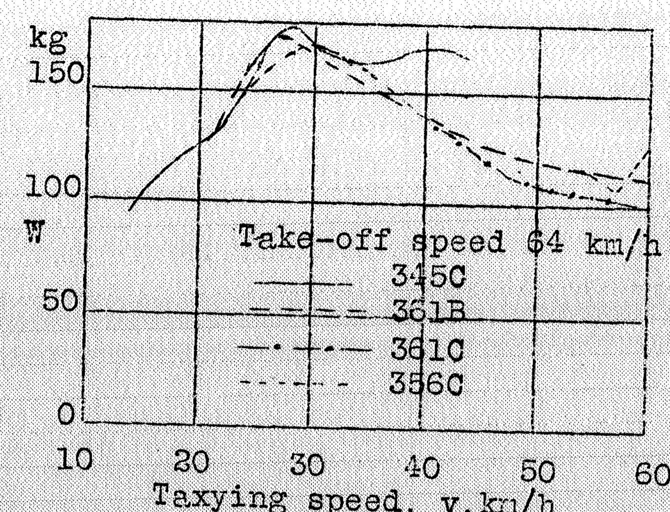

Fig.32 Water resistance of the hulls from Figs.29-31.

Model No.2450

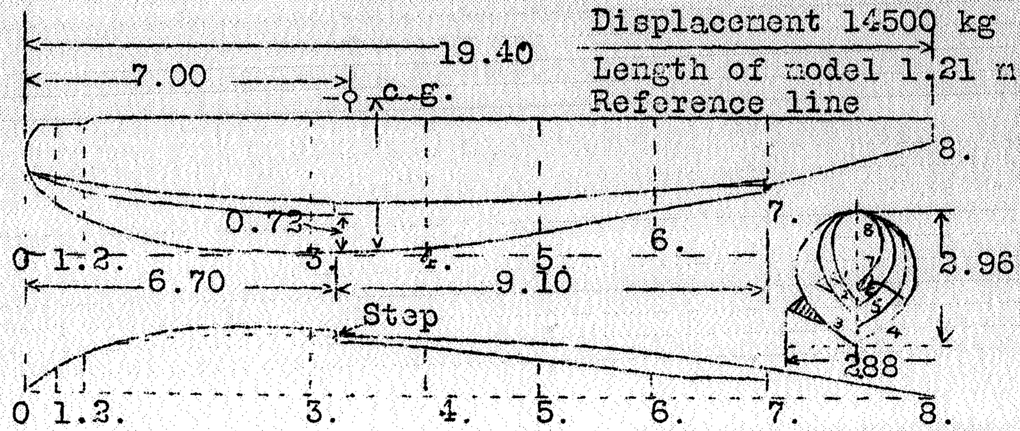

Fig.29 Lines of the English giant flying boat N.4 Titania. Without main step in the center. Also see Fig.62.

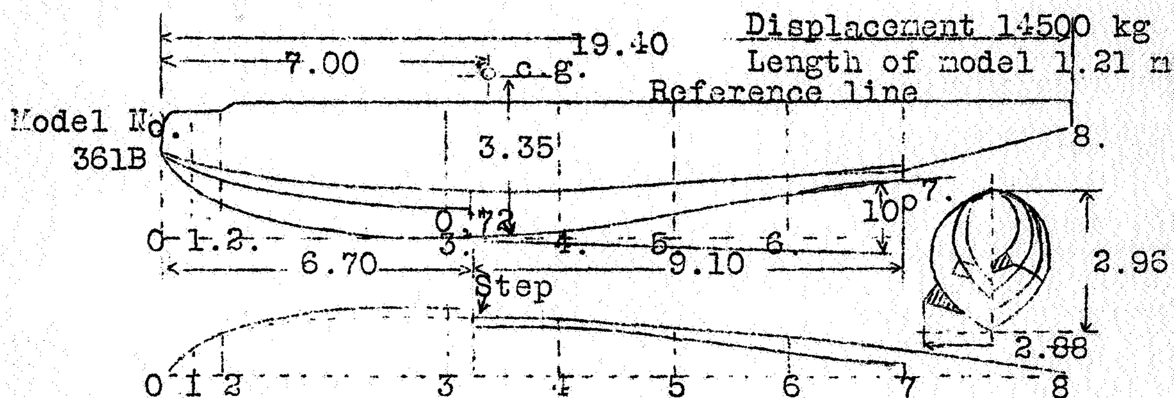

Fig.30 Lines of the English giant flying boat N.4. Titania, after changing the bottom and the step according to tank-test results. Also see Fig.52.

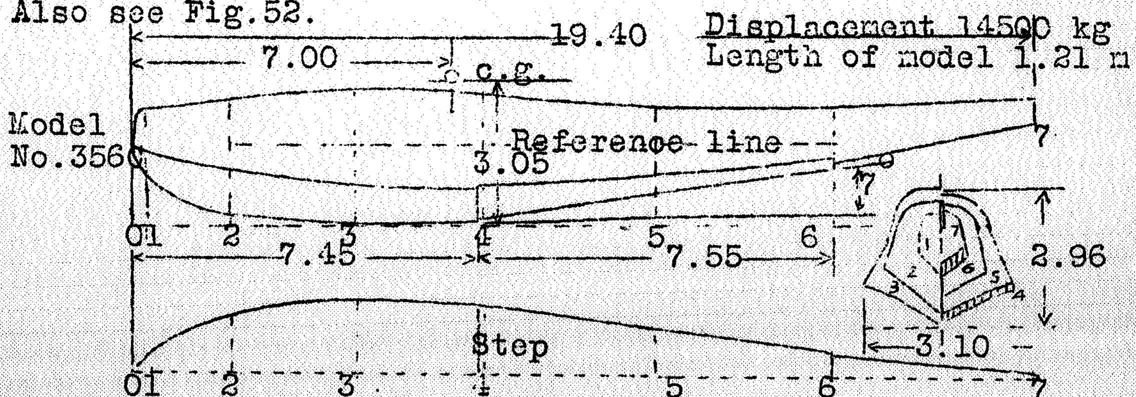

Fig.31 Lines of the English giant flying boat N.4. Atalant. Also see Fig.61.